Chapter 4

Transmission Line Constants:

→ A transmission line has resistance (🡻 current), inductance (🡻P.F) and capacitance (🡹P.F) uniformly distributed along its length.

→ These are known as constants or parameters of the transmission line.

→ The performance of the transmission line depends upon these constants.

Resistance: It is the opposition of line conductors to the flow of current through them.

$$R = \rho \frac{l}{a}$$

ρ = resistivity of the conductor material

l = length of the conductor

a = area of cross section of the conductor

→ Apart from Length, Area and Resistivity of the material, the DC resistance of the conductor is affected only by the operating temperature.

→ For electrical conductors the DC resistance increases with increase in operating temperature.

→ Alternating current tends to flow along the skin (surface) of the conductor. This phenomenon is known as Skin Effect.

→ It results in resistance offered by the conductor to the ac current (RAC) to be more in value compared to the resistance offered to the dc current (RDC). RAC > RDC

→ To reduce the influence of skin effect, stranded wire conductors are used in place of solid conductor. The stranded conductors also offer better flexibility compared to single solid conductor

→ The DC resistance of the conductor is affected only by the operating temperature. For electrical conductors the DC resistance increases with increase in operating temperature.

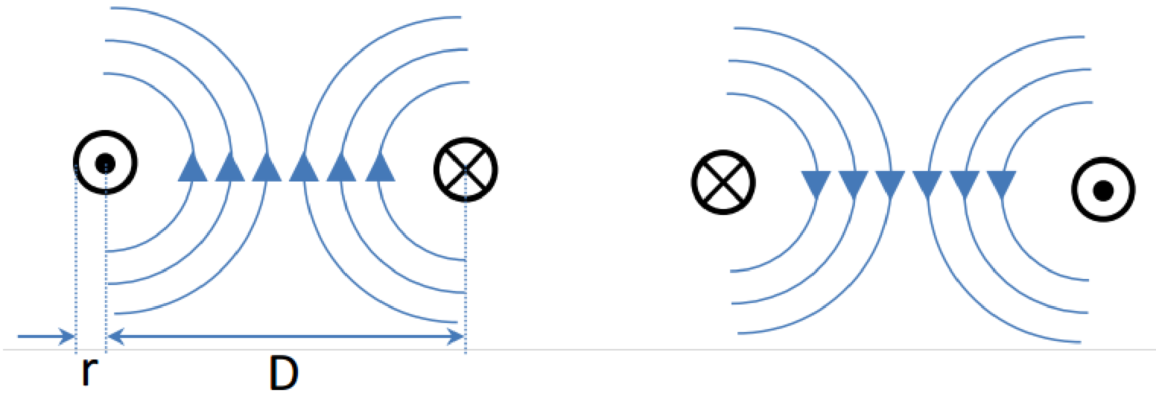
Inductance: When an alternating current flows through a conductor, a changing magnetic flux is setup which links the conductor. Due to these flux linkages, the conductor possesses inductance. $\boldsymbol{L = \frac{\Psi}{I}}$ **Henry**

ψ = flux linkages in weber-turns

I = current in amperes

Inductance of loop:

Consider the pair of conductors carrying currents in opposite directions similar to a single phase two wire circuit.



r = radius of the conductor

D=Distance between the conductors

Flux linking with any of the conductors is the sum of flux produced by the same conductor and flux produced by the other conductor when both carry current.

Self and Mutual Inductance:

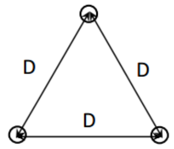
→ When the flux produced by a conductor links with itself, it results into self-inductance.

→ When the flux produced by other conductor links with a conductor it results in mutual inductance.

→ Recall the working principle of transformer.

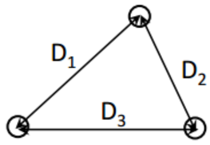
For three phase three wire with symmetrical spacing as shown in the diagram the inductance per meter length is

$$L = \left[\frac{1}{2} + 2\ln\left(\frac{D}{r}\right)\right] \times 10^{-7}\ Henry/m$$



Also for three phase three wire with unsymmetrical spacing as shown in the diagram the inductance per meter length is,

$$L = \left[\frac{1}{2} + 2\ln\left(\frac{D}{r}\right)\right] \times 10^{-7}\ Henry/m$$



Where , $D = \sqrt[3]{D1 \times D2 \times D3}$

P1- Find the inductance per kilometer of a three phase transmission line using 1.24 cm diameter conductors when these are placed at the corners of an equilateral triangle of each side 2m

P2-Calculate the inductance of each conductor in a three phase three wire system when the conductors are arranged in a horizontal plane with spacing such that D31 = 4m, D12=D23=2m. The conductors are transposed and have a diameter of 2.5 cm.

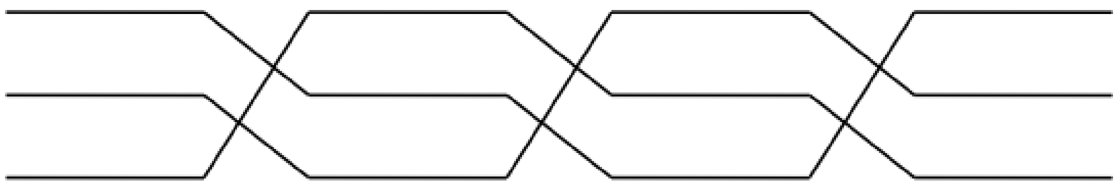
Transposition of conductors:

→ In case of unsymmetrical spaced conductors, the inductance of each individual conductor is different.

→ As a result of this unequal inductance, the impedance of each phase of the transmission line will be unequal making the system unbalanced.

→ To avoid this, in such transmission lines, the position of the conductors is changed after some distance. This is known as

Transposition of the conductors:



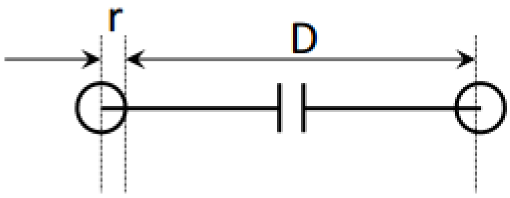
Capacitance: Any two conductors of the transmission line are separated by insulation material such as air. Thus capacitance exists between them.

$$C = \frac{q}{V} \text{ Farad}$$

q = charge on the conductor

V = voltage difference between the two conductors.

Capacitance between conductors having opposite charges on them is approximately (neglecting effect of ground) given as,



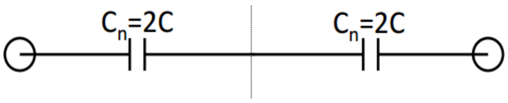
$$C = \frac{\pi\varepsilon}{ln(\frac{D}{r})} = \frac{\pi\varepsilon o\varepsilon r}{ln(\frac{D}{r})} - Farad/m$$

ε = permittivity

ε_0= permittivity of free space = 8.854 × 10-12 – F/m

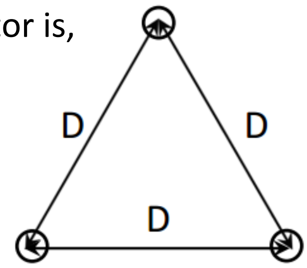
ε_r = relative permittivity of the dielectric material = 1 for air

Capacitance to neutral: It is the capacitance of each conductor with respect to a neutral point between them.



$$Cn = 2C = \frac{2\pi\varepsilon}{ln(\frac{D}{r})} = \frac{2\pi\varepsilon o\varepsilon r}{ln(\frac{D}{r})} - Farad/m$$

For three phase three wire with symmetrical spacing as shown in the diagram the capacitance to neutral per meter length of one conductor is,



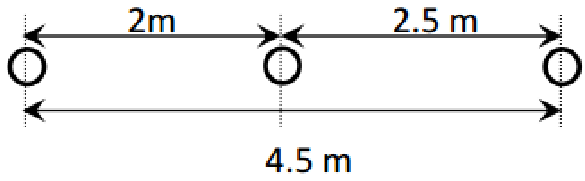
$$Cn = \frac{2\pi\varepsilon}{ln(\frac{D}{r})} = \frac{2\pi\varepsilon o\varepsilon r}{ln(\frac{D}{r})} - Farad/m$$

In case of unsymmetrical spacing:

$$D = \sqrt[3]{D1 \times D2 \times D3}$$

P3-A single phase transmission line has two parallel conductors 3 meters apart, radius of each conductor being 1 cm. Calculate capacitance of the line per kilometer.

P4-A three phase, 50 Hz, 66kV overhead line conductors are placed in a horizontal plane as shown in the figure. The conductor diameter is 1.25 cm. If the line length is 100 km, calculate



a) Capacitance per phase

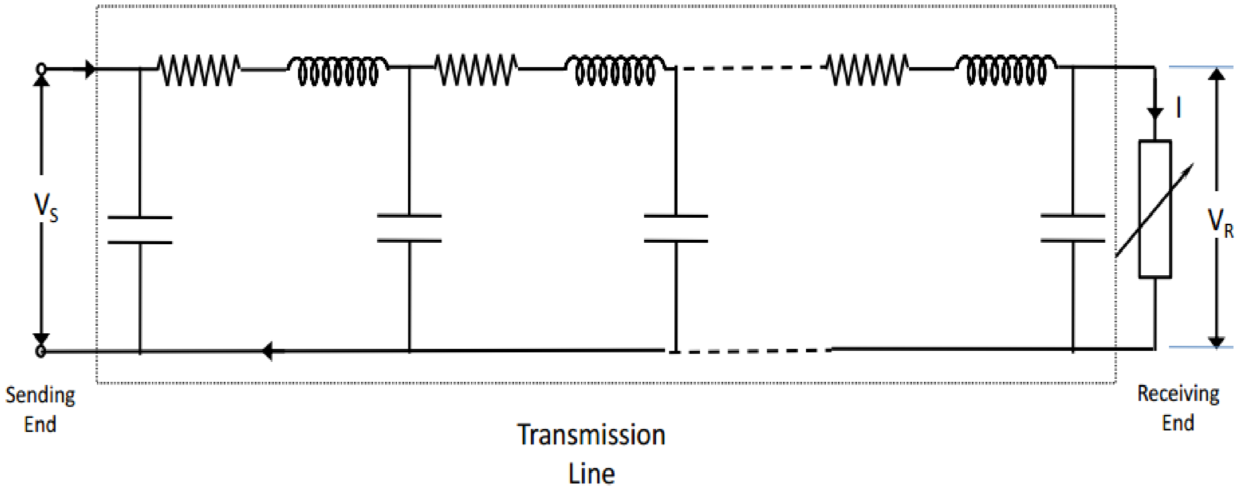
b) Charging current per phase assuming complete transposition of the line.

Representation of Overhead Transmission Lines:

→ The transmission line parameters, resistance, inductance and capacitance are uniformly distributed along the length of the transmission line.

→ Resistance and inductance form the series impedance.

→ Capacitance existing between conductors or conductors and neutral forms a shunt path throughout the length of the transmission line



Classification of transmission lines:

Depending upon how the capacitance is taken into account

The transmission lines are classified as,

1. **Short Transmission Line**: Capacitance is neglected

2. **Medium Transmission Line**: Capacitance is considered as lumped (concentrated) at one or two points in the transmission line.

3. **Long Transmission Line**: Capacitance is considered to be uniformly distributed over the entire length of the transmission line.

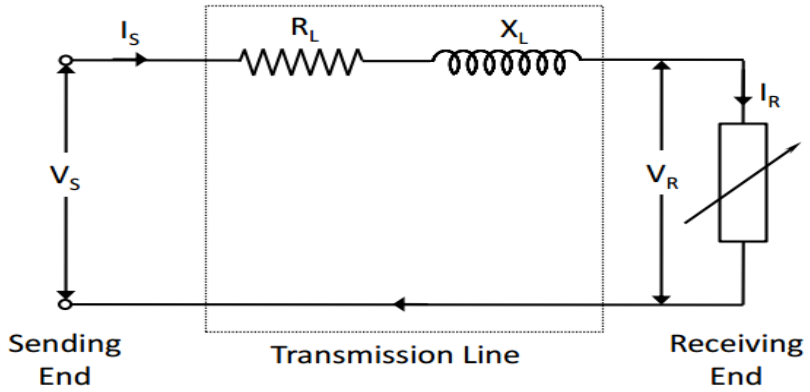
Short Transmission Lines:

→ Length: 50 km

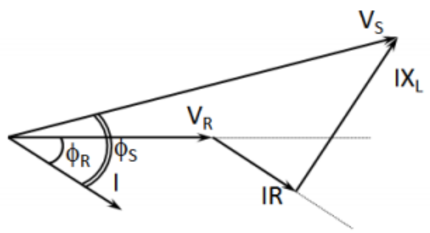
→ Line voltage: <20kV

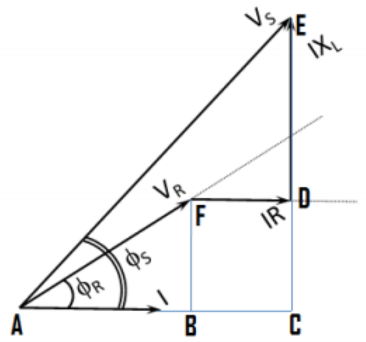
→ Due to ↓ length and ↓ voltage: Capacitance effect is ↓ so No use of Capacitance

→ $I_S = I_R = I$



Phasor Diagram for Short Transmission Line:





→ Value of (I) depends upon the (P) that the transmission line delivers to the load.

→ If the power delivered at the receiving end per phase is P_R at power factor of $\cos\phi_R$ and V_R is the receiving end voltage per phase then the receiving end current is calculated as,

$$I_R = \frac{P_R}{V_R COS\,\phi_R}$$

Ratio of the output power to the input power is called the transmission efficiency.

$$\%\ \eta = \frac{Output\ Power}{Input\ Power} \times 100\%$$

Difference between the input power and output power is the Transmission loss.

Voltage Regulation:

→ When the transmission line carries current, there is a voltage drop in the line due to the resistance and inductive reactance of the line.

→ **The difference in the voltage at the receiving end of a transmission line between conditions of no load and full load is called** voltage regulation

→ It is expressed as percentage of the receiving end voltage

$$\% \boldsymbol{Vlotage\ Regulation} = \frac{\boldsymbol{V_S - V_R}}{\boldsymbol{V_R}} \times \mathbf{100}$$

P5-A single phase transmission line delivers 1100 kW at 33kV at 0.8 pf lagging. The total resistance and inductive reactance of the line are 10 Ω and 15 Ω respectively. Determine,

a) Sending end voltage,

b) Sending end power factor and

c) Transmission efficiency

d) Voltage regulation

P6-An overhead three phase transmission line delivers 5000 kW at 22kV at 0.8 pf lagging. The resistance and reactance of each conductor is 4 Ω and 6 Ω respectively. Determine,

a) Sending end voltage,

b) Percentage of voltage regulation,

c) Transmission efficiency,

d) Sending end power factor

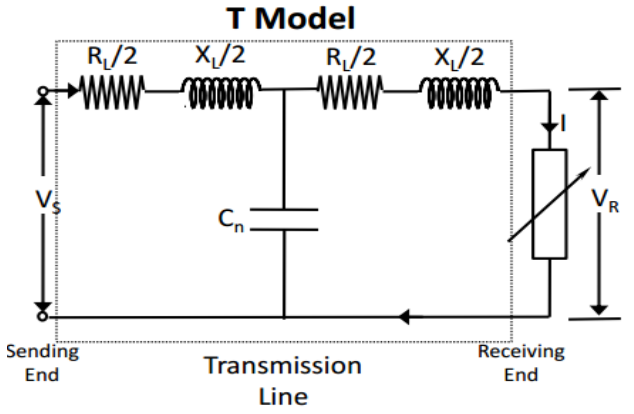
Medium Transmission Line

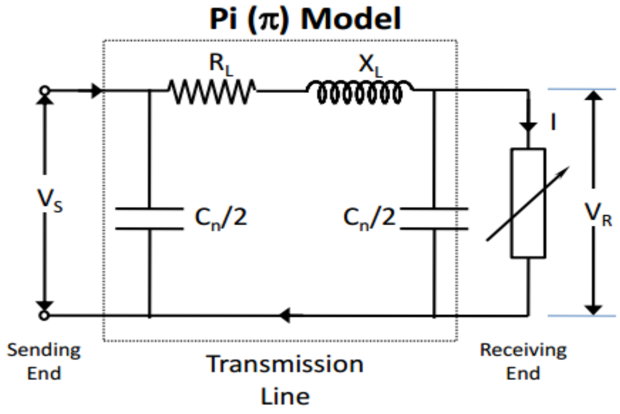
→ Length: 50 km – 150 km

→ Line voltage: >20kV - <100kV

→ Use one or two(parallel) Capacitance

→ $I_S \neq I_R$





Long Transmission Line

→ Length: > 150 km

→ Line voltage: >100kV

→ Use more Capacitance

→ $I_S \neq I_R$